# Defense Technical Information Center Compilation Part Notice

# ADP014073

TITLE: Assessment of the Efficacy of Polish Air Force Engines for Life Extension vis-a-vis Technology and Practices Prevalent in other NATO Countries

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

## This paper is part of the following report:

TITLE: Ageing Mechanisms and Control. Specialists' Meeting on Life Management Techniques for Ageing Air Vehicles [Les mecanismes vieillissants et le controle] [Reunions des specialistes des techniques de gestion du cycle de vie pour vehicules aeriens vieillissants]

To order the complete compilation report, use: ADA415672



The following component part numbers comprise the compilation report:
ADP014058 thru ADP014091

# Assessment of the Efficacy of Polish Air Force Engines for Life Extension vis-à-vis Technology and Practices Prevalent in other NATO Countries

**Col. Dr. Eng. Ryszard Szczepanik**
Air Force Institute of Technology
Instytut Techniczny Wojsk Lotniczych
ul. Ksiecia Janusza 46
P.O. Box 60
00-961 Warsaw 42
Poland

**Dr M. Witoś**
Air Force Institute of Technology
str. Ksiecia Boleslawa 6
mail box 60
01-494 Warsaw
Poland

ABSTRACT

The goal of the paper is to share PAF former and present experiences about dealing with ageing engine structures and strategies for their repair versus technology and practices prevalent in other NATO countries. Some issues of safe operation of ageing aeronautical products have been presented on the grounds of the engine-operation model. Special emphasis has been put on some aspects of both: initial tolerances in components engineering and stochastic loads which occur in the course of engine performance affect the rate of consuming the operational "fit-for-use" reserve of (sub) assemblies. The above-mentioned issues have been approached using predefined functions which represent "life" curves for individual engine components and the engine as a whole.

## 1. Introduction

The end of "cold war" and shrinking military budgets have generated the need to use the engines far beyond the previously determined life limits. There are different approaches to ensure that as much life as possible is extracted from life limited engine parts. Considering those approaches we have to remember that we don't have to much knowledge about the design details of our engine which we have on our inventory list. During previous decades we used to get all needed spare parts for our engine from previous Soviet Union engine factories which helped us without difficulties to keep our engines fit for use. There was no room for any cost effective considerations. All our jet engines of Russian origin were design to fly and maintain basing on flying hours limit. Each type of engine had strictly limited service life. After reaching this number of flight hours the engine had to be sent to overhaul base usually located in Soviet Union. It was very simple algorithm to follow.

At present we started to organise the scientific and technical preparations for implementing at least some of the western countries approaches, lifing philosophies to our engine remembering all environmental constraints which we face. The goal of the whole work is their life extension.

Of course we can not directly implement the "Safe Life Design" approach nor "Damage Tolerance Design" approach.

*Paper presented at the RTO AVT Specialists' Meeting on "Life Management Techniques for Ageing Air Vehicles", held in Manchester, United Kingdom, 8-11 October 2001, and published in RTO-MP-079(II).*

After careful studying some AGARD and the RTO/AGARD reports devoted to subject: Recommended Practices for Monitoring Gas Turbine Engine Life Consumption a well as Working Group AVT-046 Workshop papers held in November 2000 in Warsaw devoted to subject: Exchange Information About Experiences Relating to Ageing Military Aircraft Fleets with the Three New Member Nations of NATO we started to analyse the whole issue. Our efforts are directed to create step by step Engine Life Management Plan. We of course have limited time 2 years maximum to clarify the whole ELMP plan in regard to Engine Life Extension. Of course first of all we have to use the existing in PAF methodologies which are parallel or idententical with western countries approach. So first of all we have in our Air Force the data bank "San" system which enables from many years identification of causes of changes to reliability, safety, and quality of the processes of aircraft operation on the one hand, and on the other hand – determination of activities to improve the above-mentioned features.

From other point we can use the digital data recorders which reflects the Mission Analysis. Another parallel approach in regard to Engine Life Extension Program is to use fleet leaders to detect possible damage mechanism. Of course the conversion factor between EFH and LCF cycles is still unknown. The inspection frequency is based on an EFH limit. Life limited parts are scrapped once the life limit has been reached.

## 2. Brief Characterisation of the "San" System.

The San system has been intended to many-sided analyse and evaluate the aircraft's operational-phase processes. All types and versions of aircraft operated by the air force can be covered with analyses. Both individual aircraft (assemblies, components thereof) and freely composed sets of aircraft (Fig. 1) can be given consideration. The system supports the management of the operational phases of various products of aeronautical engineering.

Plentiful needs proved decisive in shaping the system and defining the scope of information to be captured. They result from:

- the problems of current and long-time operation of aircraft (the aircraft operated by the air force were flown and maintained according to the service-life strategy, and to a high degree were deprived of any care of both the Polish and the Russian manufacturers; operators had to secure the highest level of reliability and safety of operated products in their own capacity; therefore, detailed information on each failure/damage to an aircraft had to be included in the system),
- the problems arising as the fleet of military aircraft was ageing,
- the need to utilise the service lives of individual aircraft still left (i.e. to extend the by-hours-defined and calendar-based service lives).

The assessment of the reliability and quality levels of the processes of operating aircraft is usually executed by means of analysing the assessment characteristics and rates necessary to rationalise and actually manage these processes.

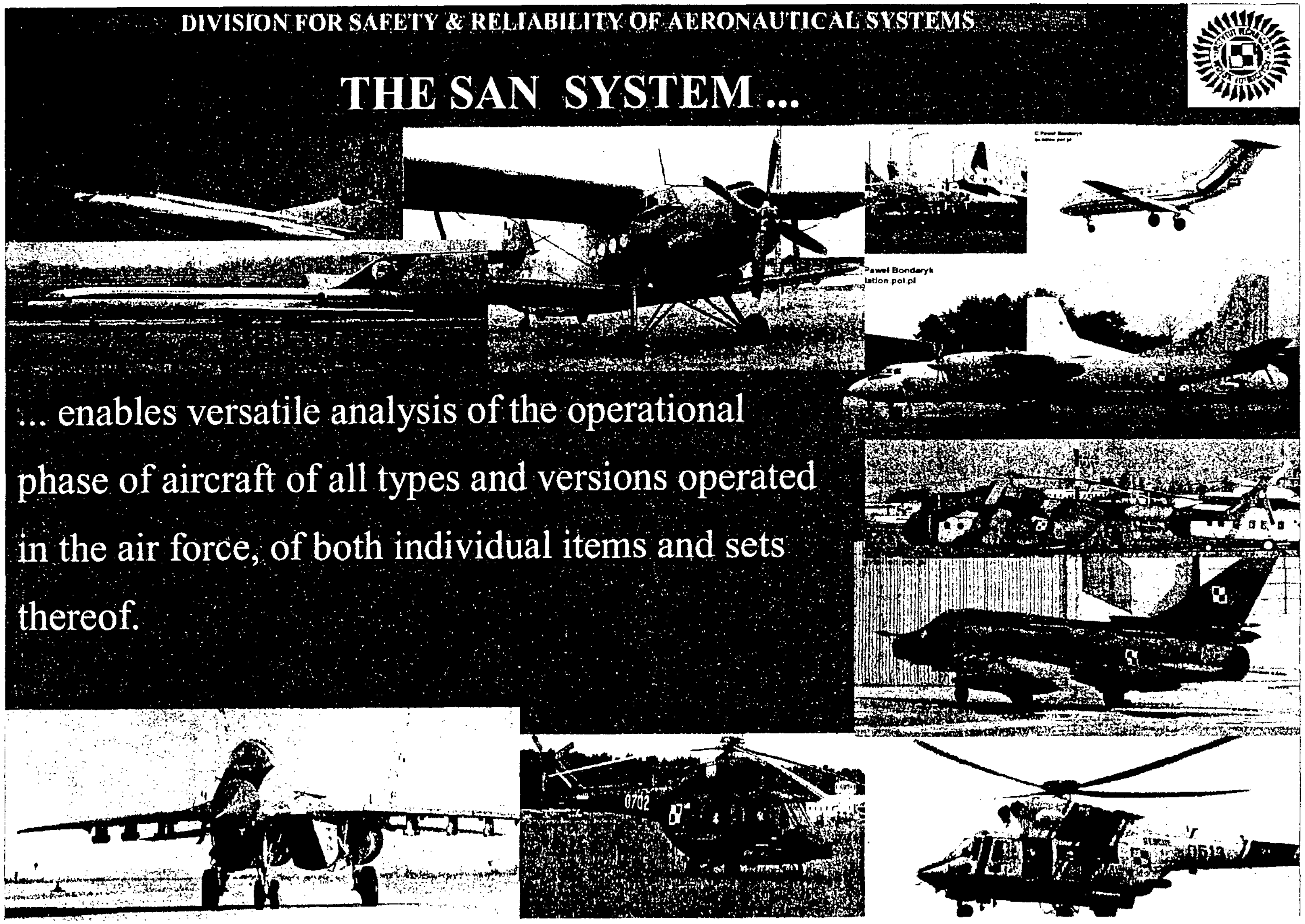
DIVISION FOR SAFETY & RELIABILITY OF AERONAUTICAL SYSTEMS
THE SAN SYSTEM ...
... enables versatile analysis of the operational phase of aircraft of all types and versions operated in the air force, of both individual items and sets thereof.
0702

Fig. 1.

The most fundamental characteristics comprise:

- the assessment of the system from the point of view of failure delectability and effectiveness to prevent them,
- the assessment of the aircraft technical availability,
- the assessment of flight safety from the technical point of view,
- substantial support of the Air Accident Investigation Board's activities,
- estimation of real service lives of aircraft and assistance to the service-life managing processes,
- forecasting some selected operational characteristics and rates, and those of safety.

Detailed objectives of the system include:

- to collect and store information in local and central data banks,
- to process the collected information according to the computational algorithms and procedures, as well as some selected probabilistic measures, estimators and statistical processing methods,
- to present – in some suitable form – a packet of characteristics and rates of the operational process to facilitate a set of rational principles of the process management to be laid, and right decisions to be made, concerning:
- the operational-phase strategies,
- frequency and scope of maintenance and the health/ maintenance status inspections,
- the fault-location processes,
- the routine maintenance and the pre-planned repairs,
- the emergency repair practice,
- weak points in aircraft structures to improve them,
- overhaul frequency and upgrade extent.

The SAN offer means of data collecting and direct loading into the computer (still at air bases which operate aircraft of interest) has to a high degree replaced techniques of `booking` the records and operating data (in use util now) and paper document circulation between individual units and command-and-control centres.

What has been provided within the system, includes:

- gathering detailed information on the course of operational phase of each aircraft,
- quick access to the resources of local and central data banks,
- good readability of the system-generated data; the effects of the processing procedures are displayed in the form of adequate reports which can be further on either printed or illustrated graphically, according to the needs,

- easiness and simplicity in using the system; there is no special training to operators required – the software has been developed in such a way as to lead the operator through (a system of directly displayed prompts, messages, descriptions has been used,
- wide spectrum of means of software protection against loading any incorrect data by the operator,
- system protection against unauthorised access,
- network communications, or that via magnetic carriers, between individual system's modules, according to hardware and financial capabilities of individual users,
- capability of selective acquisition of different, according to the module's assignment, information on individual aircraft or any set thereof.

The system has been developed with regard to the needs of, on the one hand, immediate aircraft users, decision-makers at every organisational level of the operational-phase-managing and maintenance systems, aircraft manufacturers, and on the other hand – to the needs resulting from research practice.

The SAN system has already been implemented into the Air Force of the Armed Forces of the Republic of Poland (LZS RP). It is founded on the relational database ORACLE 7/8 with more than 100 dictionary tables and tables with variable data. Applications have been developed with the ORACLE tools (i.e. OracleDeveloper/2000 and the Oracle Power Objects) and are operative in the MS Windows 98 or Windows environments.

## 3. Methodology and Experience of Operating the Ageing Aircraft Engines in PAF.

Having in view very little knowledge about the basic design criteria, as well as lack of flight test data on loads and stress spectra, lack of exact materials properties and data standards, lack of material crack-growth rate data, lack of knowledge of corrosion protection system, service experience with fatigue cracking and corrosion it makes us to create special methodology to operate safely and cost effectively our ageing turbojet engines without manufacturer support. The basic points of our approach to such task i.e. to keep our engine fleet fit to fly with high level of safety as well as cost effectively can be listed as follows:

3.1. Establishing good and reliable statistic data bank system to Engine Life Management Plan and Reliability Centred Maintenance which includes:

- engine description,
- engine life management concept
- design parameters,
- design life limits,
- inspections,
- depot maintenance,

- data tracking system,
- engine parameters monitoring,
- parts life tracking,
- documentation issues.

3.2. Conduct Mission Analysis based on installed digital recorders

The assumption is to conduct Accelerated Mission Testing on some aircraft which are called leaders. Usually such accelerated consumption of engine, aircraft life can be observed in special acrobatic teams.

3.3. Start with Analytical Condition Inspection, systematic disassembly and inspection of a representative engine sample to investigate such phenomena's like hidden defects, deteriorating condition, corrosion, fatigue, over stress, creep, to identify structurally significant, critical components whose failure could be expected to cause the engine shut down, in-flight break-up and or loss of the aircraft.

3.4. Put proper attention to engine trending and diagnostics.

We have to identify :

- mishap experiences and chronic problem areas.
- methodology to analyse service difficulty reports,
- special usage factors (for example: salt air environment),
- engine performance degradation.

3.5. Perform if needed so called "Reverse engineering" which can embrace also the Component Improvement Program.

This scope work usually embraces:

- some flight test data on loads and stress spectra,
- analysis/ test data on fatigue life,
- experience with fatigue cracking and corrosion.

## 4. Similarities and Discrepancies between Reliability so Called "Western" and "Eastern" Turbojet Engines and Their Components.

The best way to discuss these similarities and discrepancies is to use the engine diagnostic model.

The determined set of parameters which describe the engine life limit consumption together with their measuring technology can be expressed as pseudo-determined diagnostic model of the engine in the form of matrix equation

$$X(t,\bar{r}) = \Phi[Y(t)] + \eta_x(t,\bar{r}) \tag{1}$$

In this model, matrix operator $\Phi$ represents vector transformation of critical status of engine components into symptoms vector $X = X(t,\bar{r})$

Equation (1) is considered as a function of maintenance time t:

$$X = \Phi(Y) + \eta_x = \mu(t) + \eta(t) \qquad (2)$$

If the symptoms X are properly chosen so equation (2) describe so called "life" curves for individual engine components and the engine as a whole. This "life" curves can represent the development of individual defects, damages. Such interpretation we can express by equation:

$$x_j(t,\bar{r}) = \sum_{i-1}^{n}\sum_{j=1}^{m}\left[\alpha_{ij}\mu_i(t) + \eta_j(t,\bar{r})\right] \qquad (3)$$

This model shows the representation of defect development about the **i**-th engine component $\{\mu_i(t), i = 1,2,...,n\}$ in "j" symptom values $\{j, j+1,2,...m\}$ measured in the point defined by measurement place vector $\bar{r}$ in period ($0 \leq t \leq t_{defect}$)

where: $a_{ij}$ - importance coefficients about the **i**-th defect in **j**-th symptom.

$\mu_j(t,\bar{r})$ - casual disturbance of **j**-th symptom

Having in view the stochastic loads of different structural engine components we can present $\mu_i(t)$ functions as standardised "life" curves $kz_i(t)$, defined as running capability of **i**-th engine component $N_i(t,n_{rot})$ related to entry, theoretical engine capability of component $N_t(t_0,n_{rot})$

$$kz_i(t) = \frac{N_i(t,n_{rot})}{N_t(t_0,n_{obr})}$$

<u>Running capability</u> of engine component is expressed by the set of these features which describe its ability to resist maintenance, flight loads spectrum.

<u>The entry, theoretical capability</u> of any engine individual component defines maintenance, flight loads which the component was calculated and design for with fatigue resistance preservation. $Kz_i(t)$ functions are monoton decreasing functions with "0" value when component fails.

Having in view:

- wide material components properties distribution resulted from technology processes
- loads differences during exploitation process

For the same type engine group we can present set of "life" curves of any particular engine component $\{kz_i(t), i = 1,2,..., N\}$ in so called "ribbonn" function with defined confidence (fig. 2) and normal distribution.

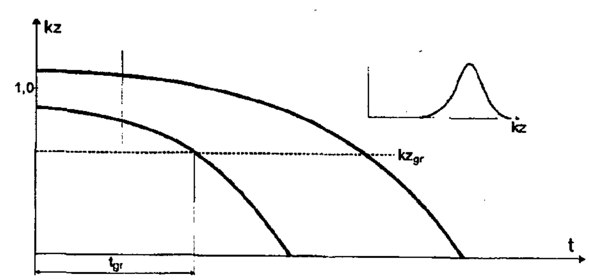


**Fig. 2.**

Summarising to extend the engine life we usually employ:

- the leaders accelerated usage concept,
- the reliable data coming from aircraft reliability data bank system called "SAN",
- mission analysis,
- analytical condition inspection,
- engine trending and diagnostics,
- reverse engineering.

Those activities are similar to western proactive except reverse engineering which is we believe unknown area. Of course there are also some discrepancies. Among them we can list the inability to create and successfully perform Engine Structural Integrity Plan (Program) ENSIP and as consequence we can not implement. Damage Tolerance Philosophy which can not be put into our maintenance practise. All these methodologies are "passive" based on assumption that we are observing the whole population of the engines. So the rules refer to the whole population. In our every day practice we observe also very often the need to prolong the engine life of individual engine. In such cases there is the need to monitor the technical condition of strictly defined critical part or parts. Sometimes after full investigation the engine defect we implement on individual basis some so called active methodologies to prolong the real engine life of individual engine. Among such cases we can mention about creation of condition monitoring system based on non-interference discrete-phase compressor blade vibration measuring method. Design such reliable and useful monitoring system shows also how important is to make proper investigations of the engine failure and to take such proper countermeasures which can meet safe and cost effective flying requirement (Fig. 3 and 4).

## 5. Conclusions.

Ageing Engine Life Extension program in PAF has to be based on investment in such practical tools like:

- Diagnostics and monitoring systems,
- Non-destructive inspection,
- Reverse engineering,
- Statistical data bank,
- Mission analysis,
- Analytical condition inspection,
- Component improvement program.

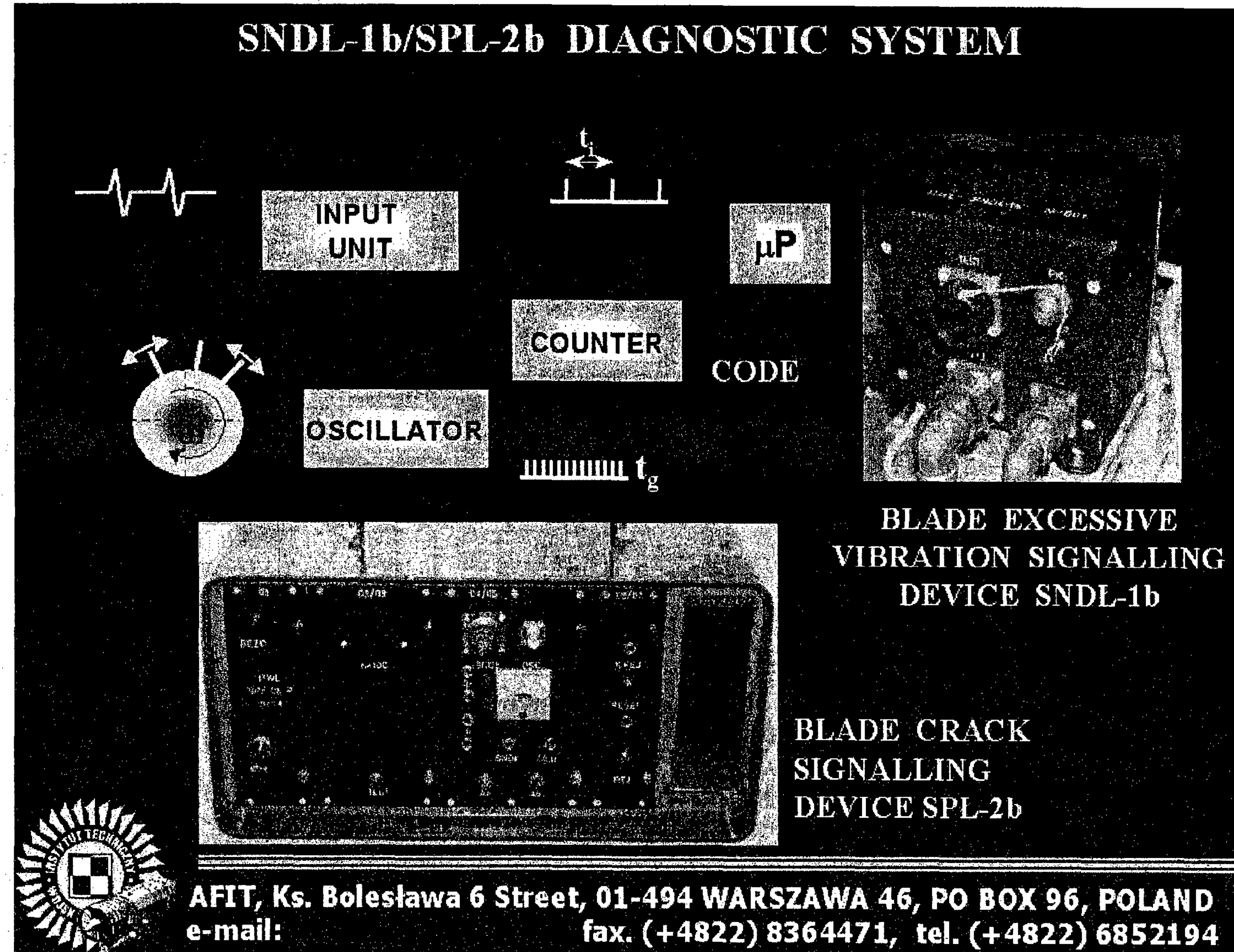
SNDL-1b/SPL-2b DIAGNOSTIC SYSTEM
$t_i$
INPUT UNIT
μP
COUNTER
CODE
OSCILLATOR
$t_g$
BLADE EXCESSIVE VIBRATION SIGNALLING DEVICE SNDL-1b
BLADE CRACK SIGNALLING DEVICE SPL-2b
AFIT, Ks. Bolesława 6 Street, 01-494 WARSZAWA 46, PO BOX 96, POLAND
e-mail: fax. (+4822) 8364471, tel. (+4822) 6852194

Fig. 3.

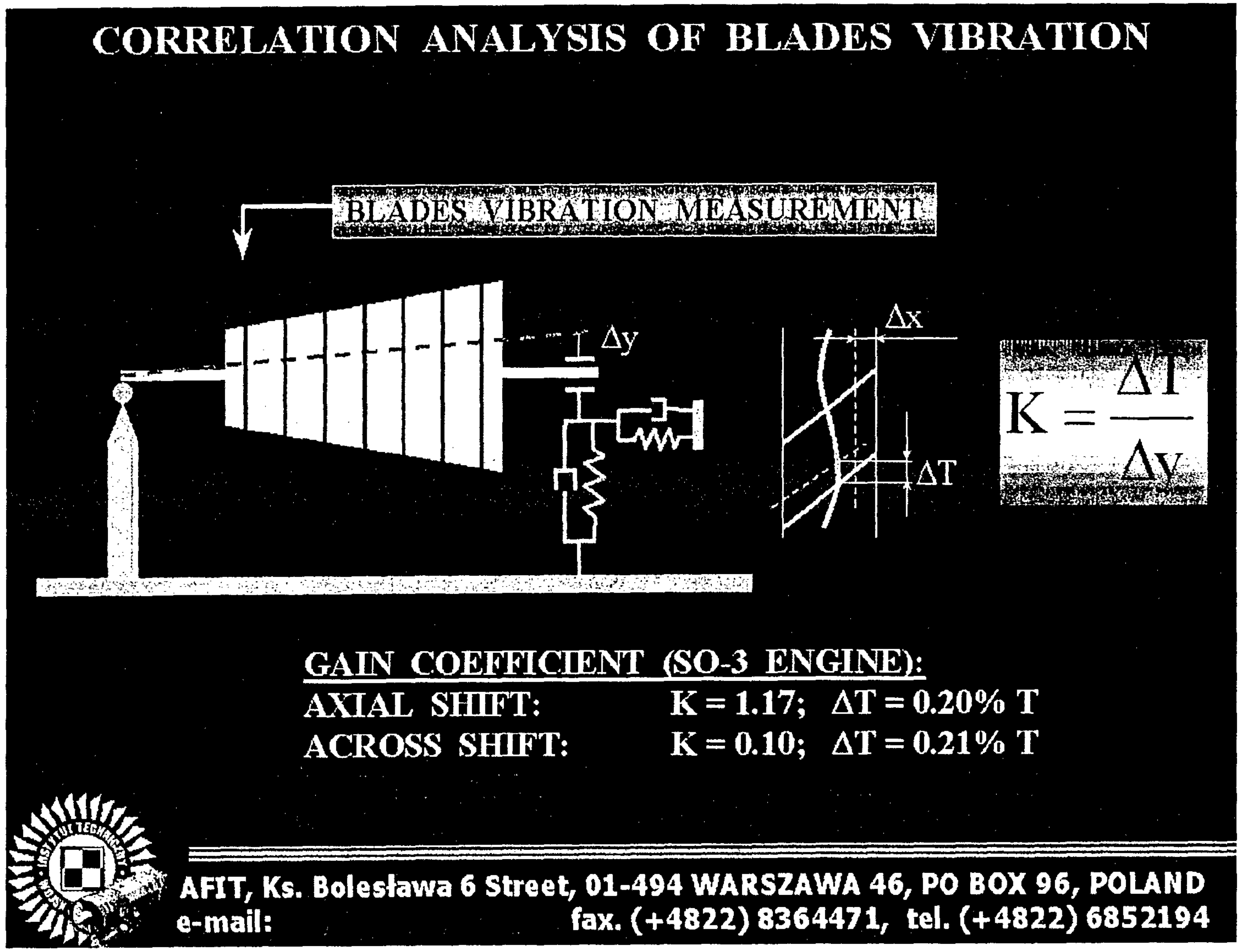
CORRELATION ANALYSIS OF BLADES VIBRATION
BLADES VIBRATION MEASUREMENT
Δy
Δx
ΔT
K = ΔT / Δy
GAIN COEFFICIENT (SO-3 ENGINE):
AXIAL SHIFT: K = 1.17; ΔT = 0.20% T
ACROSS SHIFT: K = 0.10; ΔT = 0.21% T
AFIT, Ks. Bolesława 6 Street, 01-494 WARSZAWA 46, PO BOX 96, POLAND
e-mail: fax. (+4822) 8364471, tel. (+4822) 6852194

Fig. 4.